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Published in:

Journal A: Common organ of the federation BIRA-IBRA and of the Division of Automatic Control

Publication date:

1984

[Link to publication in Tilburg University Research Portal](#)

Citation for published version (APA):

Verhallen, T. M. M., & van Raaij, W. F. (1984). Energy conservation through behavioral change: The use of natural gas for home heating. *Journal A: Common organ of the federation BIRA-IBRA and of the Division of Automatic Control*, 25(3), 144-149.

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Energy conservation through behavioral change : The use of natural gas for home heating

Theo M. M. Verhallen* and W. Fred van Raaij**

SUMMARY

Not only technical factors but also the behavior of the residents determine the energy use in the home. In a field-experimental study in the Netherlands, energy use is mainly explained by household behavior and home characteristics. Home insulation, as a home characteristic, has interesting interactive effects with household behavior. Segmenting the sample in five patterns of energy behavior, emphasizes the different determinants and policy approaches to changing household behavior with the purpose of reducing energy use in the home.

1. Introduction

Energy use in the home is determined by the technical and architectural characteristics of the house and its heating system, on one hand, and the behavior of the residents, on the other hand. The technical-architectural characteristics pertain to (1) the insulation of the *shell* (walls, windows-doors, roof, and floor), and (2) the efficiency of the *kernel* (heating system). A well-insulated shell prevents heat leakage and uncomfortable draughts.

An efficient heating system and energy source is another way of saving energy. Other relevant house characteristics are the number of rooms in use, the orientation towards the sun and the wind, the ratio of house volume and surface, attachment of neighboring houses, home insulation, and energy use of neighbors in attached homes [8]. The behavior of the residents is the other determinant of energy use in the home. Van Raaij en Verhallen [6] distinguish purchase-, maintenance-, and usage-related energy behavior. *Purchase-related* behavior refers to the consideration of the energy attribute in the purchase of durables (heating system, airconditioning, refrigerator) or home improvement (wall insulation, double glazing). Energy-efficient equipment and home improvement may be considered as household investments. A higher purchase price will be offset by lower operating costs. Cunningham and Joseph [1] and Hanna [4] investigate the acceptable payback periods and the information disclosure methods for energy-efficient equipment. *Maintenance and operating behavior* forms a second category of energy-related behavior, which is almost completely neglected in behavioral energy research. *Usage-related* behavior involved the day-to-day energy-conscious behavior of setting thermostats, using ventilation systems, opening windows and doors. Usage-related behavior consists of behavioral patterns and habits, and is, in general, hard to change. In most

households, energy behavior does not constitute a separate type of behavior but is a contingency of, or condition for, behaviors such as household work (cleaning, cooking, doing the laundry), child care, in-home entertainment (TV, visits of friends), hobbies, sleeping, and resting. This study deals with usage-related energy behavior, as a separate type of behavior for some households (the conservers) and for others, as a contingency of other types of behavior and life-style of the household members.

Verhallen and Van Raaij [9] reported a study on the effect of home characteristics and energy-related household behavior separately and conjointly on the usage of natural gas for home heating. We will discuss this study briefly.

2. The study (1)

From November 1976 through November 1977, the energy use of the home central heating system was monitored for 145 households in Vlaardingen, Holy-North, The Netherlands. In the area of Holy-North, 157 similar row houses were built by one firm : 79 with standard insulation and 78 with superior insulation. All of these houses are similar in design, except for insulation, wind orientation, and position relative to neighboring homes. Some houses are attached to another house on one side (semiattached), and other houses are attached to houses on both sides (fullyattached). Fully attached houses tend to have lower heat losses than semiattached ones. All houses have similar central heating systems, using natural gas to heat water pumped through radiators in the rooms.

(1) Financial support for this study has been provided by DSM, Gasunie, and Bouwfonds Nederlandse Gemeenten. The questionnaire design and data collection was done by Lagen-dijk Opinion Research in Apeldoorn (The Netherlands).

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This study was focussed on the behavior of household members as a major determinant of household energy use. The relationships between energy-related attitudes, household behavior, home characteristics, socio-demographics, and the actual use of natural gas for home heating were investigated.

The postulated relationships between the groups of variables are given in Figure 1. Sociodemographics include the household income, educational level and age of husband and wife, occupational level of husband, and number of children. Special circumstances are the number of bedrooms used regularly, absence during weekends or working hours, presence of guests or illness during the investigation period, and changes in household composition. Home characteristics are the degree of home insulation, the wind orientation and exposure of the building to weather influences, the position of the home relative to neighboring homes, and natural gas use for heating in neighboring homes.

The attitude measures included are related to energy consciousness, price consciousness, and the attitudes toward home comfort. Household behavior comprises all types of behavior related to energy use, such as airing out bedrooms, thermostat settings during presence or absence of household members, closing curtains at night, use of ventilation systems, and use of bedrooms for study and home work purposes.

Energy use is the actual use of natural gas for home heating during the investigation period (November 1976 to November 1977). On four occasions (November 1976, January 1977, April 1977, and November 1977) natural gas meters were read.

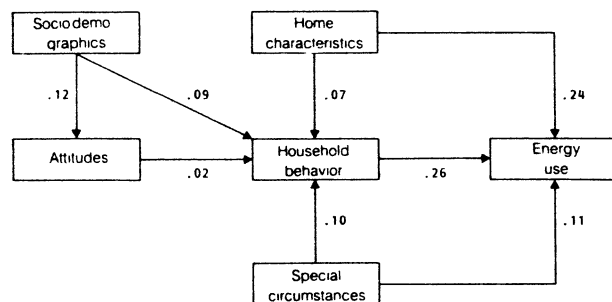
We will focus here on the relationships of home characteristics and household behavior with energy use.

Explaining energy use

As shown in Figure 1, the energy use of a household is expressed as depending on energy-related household behaviors, home characteristics, and special circumstances. We investigate these factors separately and in conjunction for each of the three periods of the study and for the total period.

Household behavior

The respondents reported 17 types of energy-related



NOTE: The numbers with arrows are proportions of explained variance of the dependent variables.

Fig. 1. Relationships among groups of variables

household behaviors. They included thermostat settings (during presence, absence, in the evening, at night, and when freezing outside); the use of ventilation systems; use of bedrooms during the day; use of radiators in bedrooms; open windows in bedrooms at night; length and type of curtains; and closing of curtains at night; use of the hallway door; airing out of bedrooms; and opening of windows in the living room. These behaviors were factor analyzed (factor analysis is a statistical technique that reveals the underlying structure of covarying variables), and six components emerged after varimax rotation, explaining 58 percent of the total variance. Positive factor scores mean more energy-wasting behavior.

The components are :

1. bedroom temperature at night, 14 percent of the variance;
2. home temperature during absence, 12 percent;
3. home temperature during presence, nine percent;
4. use of curtains, eight percent;
5. airing out rooms, eight percent; and
6. use of bedrooms, six percent.

Use of the hallway door proved to be a specific component to be added in further analysis, along with switching off the pilot flame of the central heating system when the system is not in use.

Household behavior is represented by the six principal components and by the specific components : use of hallway door and pilot flame. Stepwise multiple regression results with energy use as the dependent variable are given in Table 1. Household behavior explains 26 percent of the variance in energy use. The major variables are home temperature during absence, switching off pilot flame, bedroom temperature at night, home temperature during presence, and use of the hallway door. The latter two variables are significant in the two winter periods.

Home characteristics explain 24 percent of the variance. The major home characteristics from Table 1 are home insulation, home attachment, and the energy use of the neighbor(s).

South-wind orientation is significant in the two winter periods, whereas west-wind orientation is significant in the summer. The effect of insulation is larger during the winter : 19 percent in the November to January period, nine percent in the January to April period, and six percent in the April to November period. As the 145 houses in this study are very similar in design, for a sample of more dissimilar houses an even larger proportion of the variance in energy use may be explained by home characteristics.

Table 2 shows the proportions of explained variance of energy use in the three investigation periods and for the total period.

Household behavior explains 26 percent over the year. Home characteristics explain 24 percent over the year -27 percent in winter (November to January) and 16 percent in summer (April to November). Household behavior and home characteristics together account for 46 percent of explained variance. All variables together reach 58 percent of explained variance.

In the foregoing the relevance of home characteristics

TABLE 1. Effect of household behavior and home characteristics on energy use

Variable	Period 1 (November- January)	Period 2 (January- April)	Period 3 (April- November)	Total period
<i>Household behavior</i>				
Home temperature during absence (Component 2)	.28 ^a	.24 ^a	.36 ^a	.33 ^a
Use of pilot flame	.16 ^a	.12 ^a	.22 ^a	.19 ^a
Bedroom temperature at night (Component 1)	.11 ^a	.18 ^a	.12 ^a	.14 ^a
Home temperature during presence (Component 3)	.11 ^a	.12 ^a	.04	.09 ^b
Use of hallway door	.16 ^a	.18 ^a	.07	.14 ^a
Use of curtains (Component 4)	.02	—	.06	.03
Airing out room (Component 5)	.12 ^a	.06	—	.06
Use of bedrooms (Component 6)	.04	.03	.01	—
<i>Home characteristics</i>				
Home insulation	-.46 ^a	-.30 ^a	-.21 ^a	-.35 ^a
Home attachment	-.15 ^a	-.23 ^a	-.19 ^a	-.21 ^a
Energy use of neighbor	-.32 ^a	-.15 ^a	-.15 ^a	-.22 ^a
Wind orientation E, NE	-.02	.07	.04	.03
Wind orientation W, SW	-.06	-.05	-.16 ^a	.10 ^b
Wind orientation S	-.12 ^a	-.18 ^a	-.09	-.14 ^a
Energy use of second neighbor (if present)	-.10 ^b	-.06	—	-.05
R ² household behavior	.22	.21	.24	.26
R ² home characteristics	.27	.21	.16	.24
R ² (total amount of variance explained)	.47	.38	.36	.46

^a Significant at $p < 0.01$ ^b Significant at $p < 0.05$

NOTE : The numbers in the Table are standardized beta coefficients. For interpretation purposes it might be said that the squared beta coefficients equal the amount of variance in energy use explained by the corresponding variable.

E.g. home insulation (beta coefficient = $-.35$) explains for 11 % ($-.35^2$) of the differences in energy use between the 145 families over the total measurement period.

TABLE 2. Proportions of explained variance of energy use*

Variable	Period 1 (November- January)	Period 2 (January- April)	Period 3 (April- November)	Total period
Household behavior	.22	.21	.24	.26
Home characteristics	.27	.21	.16	.24
Special circumstances	.13	.04	.00	.11
Sociodemographics	—	—	—	.06
Household behavior and home characteristics	.47	.38	.36	.46
All variables, including attitudes	.59	.46	.46	.58

and household behavior in the explanation of energy use for home heating has been dealt with separately. The interaction between technical and architectural characteristics on the one hand with behavioral factors on the other hand will be exemplified by discussing the direct and indirect effects of home insulation on energy use.

3. Interaction of home insulation and household behavior

Home insulation seems to have two opposing effects (Figure 2). It leads to lower bedroom temperature at night (Component 1), lower home temperature during presence (Component 3), and switching off the pilot flame. However, home insulation also leads to more airing out of rooms, more opening of the hallway door,

* The unexplained portion of the variance is due to measurement error in either the meter readings, in the behavioral and home variables or due to non inclusion of other perhaps relevant factors. In social science research a figure of .58 is rather high when explaining individual differences.

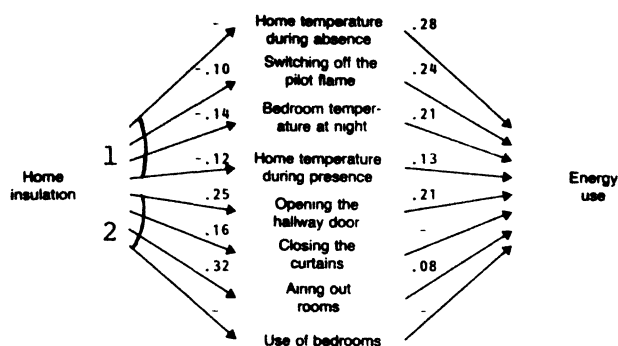


Fig. 2. The effect of home insulation on energy use via household behavior

and less closing of the curtains. Not all of these behaviors affect energy use; closing the curtains and the use of bedrooms has no effect.

The first effect of home insulation seems to be the lower thermostat settings that reduce energy use. The opposing effect, however, is the increased ventilation, opening the hallway door more often, and airing out rooms. This ventilation effect reduces the energy saving reached by home insulation.

Based on technical and architectural specifications the energy saving effect of home insulation for uninhabited houses was calculated to be 18 %. The amount of 11 % saved through extra insulation for the inhabited houses at first was a disappointment. Renewed technical computations revealed that the 18 percent difference was expected based on the assumption of no temperature differences in the home. The inhabitants of the extra insulated houses however did try to lower their sleeping rooms temperature by airing out these rooms more. This indicated the importance of the insulation properties of the ceiling between living room and sleeping rooms when insulating to a higher degree.

A similar interaction of house characteristics and household behavior has been reported elsewhere. Hamrin [3] compared the energy use of the residents of homes in two Californian suburbs "Blue Skies Radiant Homes" and "Village Homes". The first type of homes have active solar energy systems and conservation facilities. The second type of homes have passive solar energy and conservation systems, requiring the residents' active involvement by closing shutters and setting thermostats. Contrary to expectations, in the Village Homes less energy was used than the Blue Skies Radiant Homes. The Blue Skies Radiant Homes residents perceive their homes as a way to conserve energy without changing their life-style (purchase-related behavior) and are less involved in energy-conservation behavior. The Village Home people were much more active day-to-day energy conservers (usage-related behavior) and actually used less energy. This means that active involvement in energy conservation leads to a lower energy use, and also that one should "match" the type of home with the life-style of the residents.

Energy-conscious persons conserve more effectively with a solar energy and conservation system requiring their active involvement, while less energy-conscious persons conserve more effectively in home with solar energy and conservation system not requiring their in-

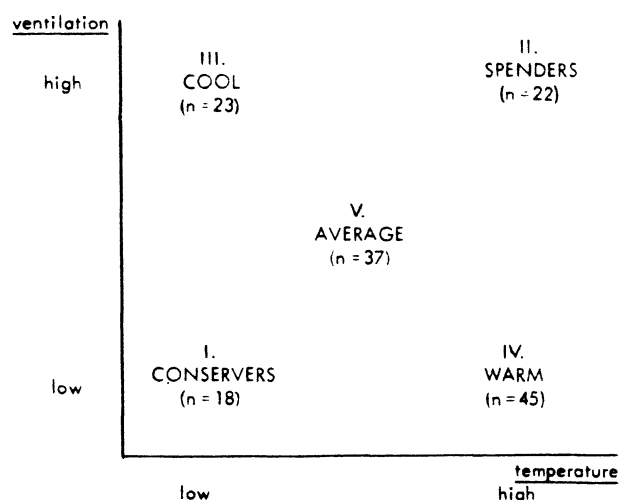


Fig. 3. The five behavioral patterns (clusters) based on temperature and ventilation.

volvement.

Darley [2] finds a similar interaction between a technical product, clock thermostat, and household behavior.

Patterns of residential energy behavior

The analyses thus far have been on averages of the total sample. The question arises whether different behavioral patterns with regard to energy use do exist and whether these patterns differ in energy use. These questions were addressed by Van Raaij and Verhallen (1983b). The respondents were classified in five predefined behavioral patterns based on their 'temperature behavior', and their 'ventilation behavior'. This corresponds with the house characteristics *Kernel* and *Shell*. The five behavioral patterns are depicted in Figure 3. We may describe the 18 respondents of cluster I by a low temperature as well as a low ventilation level : the conservers. The 22 respondents of cluster II have a high score on at least three of the four variables : the spenders. The 23 respondents of cluster III have a low temperature but are average or high on ventilation : the cool. The largest cluster is cluster IV with 45 respondents : they have average or high temperatures and low ventilation : the warm. The 37 respondents of cluster V have average scores on both temperature and ventilation : the average.

The energy use of these five groups differs considerably. The average difference between conservers and spenders is 31 percent, while the other groups are between these extreme usage levels (Table 3).

The five clusters of behavioral patterns obtained constitute a base for segmenting the population. Different energy conservation strategies/programs may be appropriate for each of the distinct segments.

The conservers (I) maintain a low temperature and a low level of ventilation in their homes. They are characterized by a higher level of education, a smaller family size, and more often the wife is also working outside the home, as compared with the other segments.

TABLE 3. The average use of natural gas of the five clusters (in m³)

Cluster	Period 1	Period 2	Period 3	Total
I. Conservers (<i>n</i> = 18)	864 (174)	696 (165)	437 (212)	1998 (484)
II. Spenders (<i>n</i> = 22)	1151 (191)	934 (146)	670 (170)	2755 (436)
III. Cool (<i>n</i> = 23)	931 (172)	803 (180)	506 (166)	2238 (468)
IV. Warm (<i>n</i> = 45)	927 (167)	768 (205)	512 (160)	2207 (423)
V. Average (<i>n</i> = 37)	979 (186)	820 (189)	605 (298)	2404 (630)
Total (<i>n</i> = 145)	963	804	555	2314

NOTE : The numbers within brackets are the standard deviations of the means.

TABLE 4. Average use of energy in the total period of the cool vs. other clusters (in m³). (For house attachment and insulation).

Cluster	Fully attached		Semi-detached		Total
	Standard insulation	Superior insulation	Standard insulation	Superior insulation	
<i>Total period</i>					
Cool (III)	2003	2057	2433	2535	2237
Other	2397	1987	2712	2439	2329

Their energy use is lower than all other segments; and large individual differences are observed in the summer period. A major explaining factor is their positive attitude toward energy conservation : a high level of energy concern and a low level of comfort concern. In this sample, the conserver segment is rather small. This segment shows the desired behavior and energy use. In an energy conservation campaign the goal should be to reinforce this type of energy behavior.

The spenders (II) maintain a high temperature and a high level of ventilation in their homes. They have a lower educational level and are more often at home. Their energy use is higher than all other segments and we observe large individual differences in the summer period. Attitudes do not explain their high levels of energy use. Attitudinal campaigns will probably not be very successful for this segment. Behavioral recommendations to lower their thermostat settings, to ventilate less, and to insulate their homes may be the best campaign strategy. Changing the energy behavior of the spenders will remain a difficult task. Home insulation might be more feasible.

The cool segment (III) maintains a low temperature but a high level of ventilation. Their energy use is intermediate. Attitudes do not explain their energy use. The cool segment uses less energy in a standard-insulated home than in a superior insulated home (Table 4), as compared between the two types of home insulation and as compared with the other segments. Home insulation has either no effect or an adverse effect on this segment. The high level of ventilation of the cool counteracts the positive effects of home insulation. In an energy-conser-

vation campaign the adverse effects of high ventilation levels should be stressed. Reduction of the level of ventilation or heat recovery in their ventilation systems may help this segment.

The warm segment (IV) maintains a high temperature and a low level of ventilation. Their energy use is intermediate. This segment is generally older and they emphasize comfort more than the other segments. It is well-known (Newman and Day, [5]) that older people prefer a higher temperature. Energy conservation campaigns should de-emphasize comfort or should advocate that good clothing instead of high temperature may not reduce comfort. In this sample, the warm segment is larger than all other segments.

The average segment (V) is by definition not deviating in its characteristics. Again we observe large individual differences in the summer period. In energy-conservation campaigns, an attempt should be made to move this segment in the direction of the conservers. The average segment requires no specific treatment but could benefit from information about lower temperatures and less ventilation.

This study shows that a segmentation approach based on behavioral patterns provides better insights in the interaction of energy behavior, attitudes, house characteristics, and sociodemographics. An attitudinal campaign should be directed to the conservers to reinforce their behavior, to the warm to de-emphasize comfort, and to the average. Home improvement and retrofitting is beneficial for the spenders but, in some ways, detrimental for the cool.

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(Continuation from p. 143)

MECHATRON INTRODUCES HIGH-PERFORMANCE LETTER-QUALITY PRINTER

Mechatron's new Series 50 letter-quality printer combines high speed, reliability and low cost in a system that offers flexibility and unusual design. The Series 50 is available through original-equipment manufacturers (OEMs) only. The new Mechatron printer is designed to be plugged into any personal, micro- or minicomputer, as well as advanced word-processing systems. A Centronics parallel communications interface (IBM PC-compatible) is standard. Many optimal interfaces are available, and an internal board slot is available for OEM custom interfaces. Optional accessories include a bidirectional forms tractor sheet feeder and serial interface card.

The Series 50 operates at 50 cps at 12 pitch using IBM-compatible "AAA" text. It offers 10, 12 or 15 pitch and handles up to 271 characters with proportional spacing. Maximum paper width is 15 inches. The bidirectional printer provides automatic centering and justification. The Mechatron Series 50 incorporates standard replacement components that are readily available. The daisy-wheel printing element is the Diablo cartridge type (Hy-Type II) in either multistrike film or endless-loop fabric ribbon. Silver Reed or Mechatron print wheels are compatible with the Series 50.

Weighing less than 33 pounds, the new Mechatron printer is constructed with a cast aluminum base that acts as a heat sink and eliminates the need for a fan. The

Series 50 runs silently between print jobs. Cables housed in channels within the aluminum base are shielded from static discharge and EMI radiation. The Series 50 has approximately 300 parts, about 40 percent fewer than comparable printers based on earlier technology. The Mechatron system has a MTBF of more than 5,000 hours and a mean time to repair of 15 minutes. Mechatron Systems Inc., of Sunnyvale, manufactures and markets letter-quality daisy-wheel printers to original-equipment manufacturers. Mechatron is a subsidiary of TeleVideo Systems Inc. In Europe, the Series 50 is marketed by TeleVideo Systems Inc. in Amsterdam and Paris.

PREPARATIONS FOR THE X. IMEKO WORLD CONGRESS

The Preparatory Committee of the 1985 Congress of IMEKO met recently in Budapest with the participation of the President, Mr. *Ludvik Kuhn*, the Secretary General *György Striker* and other representatives of the National Organizing Committee and the Secretariat. In response to the Call for Papers issued by the International Measurement Confederation, numbering at this time Member Organizations from 27 countries, a total of 501 Congress papers have been received from 31 countries. The International Paper Selection Board has the task to select of those a total of not more than 250 papers for technical sessions and poster-presentations. Plenary survey papers are under preparation about the role of measurement in the increase of efficiency and productivity, in material saving, in the conservation of environment, in quality control and about novel sensors in roboters.

The General Council of the International Measurement Confederation will hold its 27th General Council Session to discuss the report of the chairman of the 146 member International Paper Selection Board, consisting of specialists from 23 countries. This will lead to the shaping of the final programme of the jubilee 10th IMEKO World Congress, to be held in Prague in 1985. The preparation and issuing of the Second Circular and final invitation is planned for the summer months. Those interested in receiving further details may turn to the Secretariat : 1371 Budapest, POB 457.

BERLIN CONTINUING EDUCATION PROGRAM BECEEP Forum & Symposium on ELECTRONIC BANKING at the International Congress Center – ICC Berlin

The Forum & Symposium on ELECTRONIC BANKING which took place at the International Congress Center Berlin from May 15-18 brought together more than 70 experts in banking automation from all over Western Europe and the U.S. and 8 manufacturer companies which stressed on the high technology product in their line which, to their judgement, helps better promote the banking services in the coming years.

(Continued on p. 154)